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SECOND QUARTERLY REPORT

OF

RESEARCH AND DEVELOPMENT ON CELLS WITH BELLOWS CONTROLLED ELECTROLYTE LEVELS

SEPTEMBER 10, 1964 TO DECEMBER 10, 1964

CONTRACT NAS5-3813

ESB REPORT NO. E-3-65

Prepared By:

THE ELECTRIC STORAGE BATTERY COMPANY
MISSILE BATTERY DIVISION
RALEIGH, NORTH CAROLINA

FOR THE

GODDARD SPACE FLIGHT CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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Second Quarterly Report
NASA Contract No. NAS5-3813
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SUMMARY

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Cycle tests on 4 AH sealed, nickel cadmium cells containing heat sealed plastic pillows as the operating electrolyte level controlling bellows device have been performed successfully on 24-hour and 2-hour orbits at a 70% depth of discharge. A lag in oxygen recombination creates maximum cell pressures and minimum electrolyte levels during early discharge with minimum pressures occurring during early charge.

Rapid electrolyte drainage from partially flooded plate packs accelerates recombination. The best combination of electrolyte and separator in tests to date is 20% KOH and open-weave mono-filament nylon cloth.

Rectangular, partially inflated plastic pillows have demonstrated on an accelerated test basis 25,000 cycles of expansion and contraction under cell conditions at room temperature and with an expansion efficiency $\Delta V/V$ of 0.58.

Author

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I. INTRODUCTION

Although work in the first quarter demonstrated the possibility of electrolyte level control in the Cd/KOH/NiOOH system, tests also revealed a prime problem area in the slow recombination of oxygen gas at the negative plate. The improvement of recombination rate was clearly indicated, especially through selection of a separator and a cell electrolyte volume that would not leave the negative plates over-wet after a simple drain.

Work in the second quarter, confined chiefly to Task 1, the Cd/KOH/NiOOH system, was directed toward three objectives:

a. The optimizing of all possible cell parameters for use in the fifteen 6 ampere-hour bellows evaluation cells.

b. The selection and procurement of the best available metallic bellows along with improvement of non-metallic bellows substitute.

c. The design and fabrication of 15 lucite cell containers with bellows chambers along with assembly of the plate groups for the 6 ampere-hour test elements.

All experience gained with metallic bellows and bellows substitutes is directly applicable to the objectives for the Cd/KOH/AgO performance of Task 2.

The selection of a bellows manufacturer with capability for electroforming bellows in rectangular, round or other shapes will be used to advantage for incorporating the pressure activated electrical switch of Task 3.

2. WORK ACCOMPLISHED DURING SECOND QUARTER

2.1 Task 1 - Feasibility of Electrolyte Level Controlled by Bellows In A Sealed Cd/KOH/NiOOH Cell. -

2.1.1 Cell Parameter Study. - In the first quarterly report (1), four approaches were suggested for the improvement of recombination:

a. Increase negative plate area available for recombination.

b. Increase solubility of O_2 in electrolyte by decreasing concentration.

c. Decrease the volume of O_2 in the cell by decreasing the free space around and above the cell pack.

d. Decrease the effective thickness of the layer of electrolyte on the negative plate.

In its entirety this study encompassed five distinct test series. At the outset only two series were planned, Series "D" and "E", to evaluate the best available separator along with three different electrolyte concentrations and two electrolyte levels, and to study pillow action. Unexpected high cell operating pressures dictated the inclusion of three sub-series under "D". New pillow techniques and materials brought the addition of Series "F" and "G". The acquisition of promising new separator materials resulted in their evaluation by Series "H", "I", and "J".

Table I presents an outline of the most pertinent test and cell details for the nine major tests. The attempt was made, where possible, to evaluate several parameters simultaneously and at the same time learn the eccentricities associated with bellows action.

The test cells used in this study were composed of 4 AH, sintered plate Ni-Cd elements in lucite jars equipped with a pressure gauge and needle valve and fitted with a detachable bellows chamber below the element. The same two cells, Nos. 3 and 4, were used throughout. The electrolyte concentration was the only deliberately imposed difference between the two cells. Each contained a set of four polyethylene 4 mil pillows, with two large ones folded to line the broad walls and two small ones to line the narrow walls of the rectangular chamber.

2.1.1.1 <u>Electrolyte Concentration Effect in 24-Hour Orbit Tests.</u> - <u>(SERIES D-1 AND D-2)</u>

a. Cycle Regime: Charge 22 hours at 250 mA (1.37 C).
Discharge 2 hours at 1.4 amps (0.7 C).

b. Separator: Double layer of 4 mil, 120 mesh, nylon, mono-filament cloth with a 5.4 mil aperture.

c. Electrolyte Level: Maximum possible height of 10% plate immersion at 20" Hg vacuum.

d. Electrolyte Concentration:

Series D-1 (5 cycles) - Cell No. 3 contained 25% KOH
Cell No. 4 contained 31% KOH

Series D-2 (6 cycles) - Cell No. 3 contained 25% KOH
Cell No. 4 contained 20% KOH

Table II lists the electrolyte level, cell pressure and time of occurrence for maximum and minimum cell pressure in each cycle. Several points are noteworthy:

a. A lag in recombination causes the <u>pressure maximum</u> to occur near the end of the charge period and the <u>pressure minimum</u> to appear near the first 10% of the 22-hour charge. This effect during one full cycle is shown in Figure 1 along with the corresponding change in electrolyte level due to action of the plastic pillows used as the bellows devices in each cell.

b. An effect of electrolyte concentration on cell pressure is clearly shown in Figure 1. Average values for all cycles are listed as follows:

	31% KOH (5 Cycles)	25% KOH (11 Cycles)	20% KOH (6 Cycles)
Maximum Pressure =	23.0 PSIA	17.6 PSIA	14.7 PSIA
Minimum Pressure =	5.5 PSIA	4.1 PSIA	1.9 PSIA
Plate Immersion at Minimum Pressure Point, % =	--	3%	6%

Note also in Figure 1 how the relatively high minimum pressures have depressed the maximum electrolyte level in the case of 31% KOH.

2.1.1.2 Electrolyte Concentration Effect In 2-Hour Orbit. - (SERIES D-3)

The conditions selected for the 2-hour orbit cycle tests consisted of the following:

a. Cycle Regime: Charge 90 minutes at indicated rate. Discharge 30 minutes at 5.6 amps (0.70 C).

b. Separator: Same as 24-hour test series.

c. Electrolyte Level: Same as 24-hour test series.

d. Electrolyte Concentration: Cell No. 3 = 25% KOH
Cell No. 4 = 20% KOH

Two cycles at the 3.73 ampere charge rate to a 1.4 C input produced excessive pressure and Cell No. 4 containing 20% KOH was re-evacuated after a 19-1/2 hour open-circuit stand.

Four cycles at the 2.61 ampere charge rate to 140% of the previous output produced excessive pressures and were followed by re-evacuation of Cell No. 4 containing 20% KOH.

Eleven cycles at the 2.05 ampere charge rate to 110% of the previous discharge output were run successfully without a build-up of pressure over 10 psig.

A test evacuation of both cells at the end of the series produced full pillow response in cell No. 3 to 10% immersion but only partial response in Cell No. 4 to 2-1/2% immersion. Examination revealed leaks in 3 of the 4 pillows in this cell. The causes of these leaks will be discussed in a later section of the report.

Table III lists the maximum and minimum cell pressure with time of occurrence in each cycle. Note how the relatively high minimum pressure throughout this series kept the level below the plate bottoms except for the periods of open-circuit recovery.

A difference in the average maximum and minimum cell pressures was found for the 11 cycles, which again shows lower values for the lower concentration of electrolyte:

		25% KOH	20% KOH
Maximum Pressure	=	16.8 PSIA	14.3 PSIA
Minimum Pressure	=	9.9 PSIA	6.7 PSIA

Two-hour orbit cycling demonstrates an electrolyte concentration effect with lowest pressures and the best electrolyte level control in 20% KOH.

A lag in recombination is even more pronounced in the 2-hour orbit test with the pressure minimum appearing during the first 1/3 of the charge period and the pressure maximum at about the first 17% of the discharge period.

An increase in electrolyte level was dictated by the "D" series tests. The 10% immersion of plates initially was proved to be too low. As cell pressures developed the electrolyte level dropped to a position 19 to 22 mm below the bottom of the plates giving performance essentially equivalent to a drained cell pack.

2.1.1.3 Electrolyte Concentration Effect In 2-Hour Orbit Test At A Significant Electrolyte Level (Series "E"). - To determine the effect of electrolyte concentration at a significant electrolyte level, the following test conditions were imposed:

a. Cycle Regime: Charge 90 minutes at 2.05 amperes.
Discharge 30 minutes at 5.6 amperes.

b. Separator: Same as 24-hour tests.

c. Electrolyte Level: 72% plate immersion at 26" Hg vacuum.

d. Electrolyte Concentration: Cell No. 3 = 25% KOH
Cell No. 4 = 20% KOH

Thirty-seven uninterrupted cycles were run. Cell pressures and electrolyte levels were monitored closely at the beginning (Cycles 1 through 4), near the middle (Cycles 13 through 16) and near the end (Cycles 25 through 28). Figures 2 and 3 are plots, respectively, of these readings.

Several points of interest are clearly discernible:

a. Throughout the entire test, the cell with the lower electrolyte concentration (20% KOH) had the lower operating pressures.

b. During the first four cycles, a steady build-up of operating pressure occurred. After ten cycles the pressures had stabilized at a level slightly above the fourth cycle values.

c. After stabilization of operating pressures, the advantage of 20% KOH became more pronounced as shown by the greater range between the maximum and minimum pressure curves.

d. A recombination lag is again evident with the pressure maxima in early discharge and the minima at about mid-charge. The pattern is the same throughout for both electrolyte concentrations.

e. The electrolyte level response in the first four cycles was generally as expected with the maximum levels coinciding with the pressure lows. The initial high level was reduced in the first cycle to about 10% immersion and remained at or below this level for the entire cycling period. A number of disparities are evident in the latter stages of cycling:

1. The level in cell No. 4 (20% KOH) remained below the plate bottoms during most of the discharge periods. The periods of maximum level occurred during charge, became progressively shorter and reached levels of only 1% immersion. The minimum levels occurred generally in phase with the pressure maxima.
2. The level in cell No. 3 (25% KOH) ranged at or above plate bottoms and showed maximum levels out of phase with pressure minima. The maximum levels occurred near the start of discharge and reached peaks of about 5% immersion.

The average maximum and minimum cell pressures are higher for this test as compared with the preceding drained element tests:

		25% KOH	20% KOH
Maximum Pressure	=	31.8 PSIA	24.7 PSIA
Minimum Pressure	=	22.8 PSIA	16.1 PSIA

After the last discharge the cells were allowed to stand on open-circuit, and the pressure decay and level response were monitored for a 22-hour period. The data are plotted in Figure 4.

Cell S/N 4 (20% KOH) showed lower pressures throughout most of the decay period and a more rapid rate of level recovery during the first half of the period. Both cells showed nearly complete recombination of cell gas during the decay period monitored.

In a test re-evacuation, neither cell showed a return to original electrolyte levels with cell No. 4 showing the greater loss of response. Subsequent examination of the pillows showed seam leaks in the two small pillows of cell No. 4. The pillows of cell No. 3 were apparently intact but seemed somewhat deflated, suggesting the possible loss of trapped air by diffusion through the 4 mil polyethylene film.

Test Series "F" was initiated for the purpose of making a quick evaluation, under the same test regime, of what appeared to be a promising pillow material in the form of flexible tubing. The test was abandoned after 10 cycles upon evidence of electrolyte attack.

2.1.1.4 Ratio of Charged Active Materials. - Dennis Turner (2) has indicated a definite relationship between recombination rate and state-of-charge of the negative plates. By increasing the ratio of charged negative active material to charged positive active material, he visualizes greater areas of cadmium made available for reaction. The maximum possible ratio with the cells in this study is 1.5, and the operating initial ratio has been 1.13. It is proposed, therefore, as a part of the work of the third quarter to evaluate this parameter at ratios of 1.3 and 1.4.

2.1.2 Evaluation of Netting and Cloth Separator Materials. -

2.1.2.1 General. - As brought out in the first quarterly report, the whole concept of performance improvement through regulation of electrolyte level was found to hinge on the capillary properties of the separator. Evidence for this appeared in the failure of micro-porous sheet insulated cells to show capacity loss after simple draining of electrolyte and also by their inability to withstand sealed overcharge. This behavior is attributed to the substantial wicking and absorptive powers of the microporous material where saturated pores supply an ample reservoir of electrolyte for discharge but present a formidable barrier to gas passage.

A search was conducted for separator materials with a balance of capillary properties which would allow rapid drainage to quickly form gas passages but still retain enough electrolyte to provide a thin film of electrolyte suitable for ionic and gas transfer.

Many samples of polyethylene and polypropylene netting were obtained, most being unsuitable due to large openings and excessive thickness. Two of the most promising materials were selected for the test: DuPont Type 15 ADS 129 Vexar polyethylene netting, 23 mils thick; and Nalle Company's "Rice Bag" polyethylene netting, 16 mils thick. In addition, an open-weave type of mono-filament nylon cloth was secured. It is Albert Godde Bedin Company type 8-M screen cloth, 96 mesh with a 6.3 mil aperture and 4 mils thick, to be used in a double layer.

2.1.2.2 Effect of Electrolyte Level On Discharge Capacity. - A three cycle, manual test was run for each separator material using cells No. 3 and No. 4 in the open condition. Test conditions selected were as follows:

a. Cycle Regime: Charge the flooded cell in all cycles for 16 hours at C/10 (400 mA).

b. Open-Circuit Stand: For 4 hours.

c. Discharge: At C/2 (2 amps) to 1.00 volt per cell.

d. Cycle No. 1: Discharge at flooded level.

e. Cycle No. 2: Discharge at 50% flooded level. Flood the cell and run a residual discharge at 1 ampere to remove the same total output as in Cycle 1.

f. Cycle No. 3: Discharge at 10% flooded level.

g. Electrolyte Concentration: Cell No. 3 = 25% KOH
Cell No. 4 = 20% KOH

The ampere hour capacities obtained during the three discharge capacity tests are listed for each separator material in Table IV.

The discharge voltage characteristics are plotted in Figure 5.

The two net materials show a definite decrease in capacity with decrease in electrolyte level. The coarse nylon cloth shows a small capacity to level relationship which suggests the possibility of a greater effect at higher discharge rates and lower temperatures.

The thicker nets do not adversely affect the discharge voltage "plateau" as compared with the thinner cloth separator at this particular rate (C/2).

There is little difference in voltage characteristics between the 25% and 20% KOH cells. Where a difference does appear, the 20% concentration gives the higher values.

2.1.2.3 <u>Effect of Separator on Sealed Overcharge Characteristics</u>. - At the end of each 3-cycle discharge test, the cells were flooded, discharge to zero volts at the C/5 rate and continued into reverse charge to prepare the negative group for sealed operation. After a 4 to 5 hour open-circuit stand, the cells were drained to the 10% plate immersion level, evacuated to 28" Hg and sealed. A single 4 mil polyethylene pillow 1-7/8" X 2" with 1.5 cc trapped air was placed in the chamber of each cell. The pillow caused the level of electrolyte to rise during cell evacuation to the completely flooded stage. With the cells in this condition, a charge at C/10 (400 mA) was given followed by a period of overcharge at C/20 (200 mA).

Details of the sealed charge including AH input, voltage, pressure and electrolyte levels are listed in Table IV

The variation of cell voltage, pressure and level with time of charge can be seen in Figure 6 for cell No. 3 (25% KOH) and in Figure 7 for cell No. 4 (20% KOH).

For each overcharge the following limits were set for manual termination:

a. Cell Voltage = 1.55 V

b. Cell Pressure = 50 PSIG

c. Time = 24 hours

The time limit was arbitrarily set at 24 hours to speed the course of the test program.

Overcharge testing with 23 mil DuPont Vexar net was terminated in cell No. 3 by voltage. It was terminated in cell No. 4 at 24 hours with the voltage appearing to level at 1.51 volts and the pressure continuing to rise at 31 PSIA

Overcharge with 16 mil Nalle netting was ended in cell No. 3 by a voltage of 1.54 volts which gave a slight indication of leveling. It was ended in cell No. 4 by a pressure of 64 PSIA with a stabilized voltage of 1.52 volts per cell.

Overcharge with 8 mils of 96 mesh nylon cloth was carried at C/20 for both cells to a total input of 12.4 ampere hours. At this point the voltage was 1.42 for both cells and the pressure stood at 13 PSIA for cell No. 3 and 16 PSIA for cell No. 4. The total charge period was 44 hours.

The charge rate for both cells was then increased to C/10 (400 mA) and continued 48 hours more to a total charge input of 31.6 AH. At this point the voltage of cell No. 3 had increased gradually to 1.49 volts and the pressure had stabilized at 22 PSIA. Cell No. 4 at the same point had a stabilized voltage of 1.45 volts but a pressure which had increased steadily to 62 PSIA.

In this test the electrolyte levels were not monitored reliably and Figures 6 and 7 show only those few measurements that were considered accurate. Enough points were obtained, however, to give the following approximations of level during overcharge:

Separator	Cell No. 3 (25% KOH)	Cell No. 4 (20% KOH)
Vexar Netting	24% Immersion	20% Immersion
Nalle Netting	30% Immersion	24% Immersion
AGB Nylon Cloth	12% Immersion	18% Immersion

This test indicates AGB Type 8-M nylon cloth in double layer as the best available separator material on hand.

2.1.2.4 Comparison of Physical Properties. - Beside the simple expedient of trial and error in the search for the best separator material for bellows action cells, it appeared likely that an examination of material geometry as related to surface forces when in contact with electrolyte would help to define some of the characteristics needed.

Previous study of separator materials (3) has recognized the significance of physical makeup, for example, where absorbency of electrolyte to a considerable degree is shown by woven cloths, such as nylon, which has no wicking powers.

During the search for a coarse weave nylon cloth, a closely graded line of Teflon screening in 16 sizes was found. Since this line covers a range of aperture sizes from the netting sizes at one extreme to nylon cloth at the other, it was believed that one of the intermediate grades could easily approach the optimum mesh size.

Table V was prepared to list some of the physical and dimensional features of nine materials, including very fine mesh Teflon (screen) at one extreme, Vexar and Nalle netting at the other extreme, two nylon mono-filament cloths (120 and 96 mesh), and four intermediate grades of Teflon screen.

Table V lists the overall thickness, mesh dimension, ratio of mesh area to thickness ("pore" depths), some data on electrolyte absorbency and drainage, and height of the electrolyte column observed after drainage.

By considering the cell test data gathered thus far on separator materials and the data given in Table V, it is believed that the 67 mesh Teflon screen, type AGB 9-60-250, should closely approach the optimum. Details of the consideration leading to this prediction are as follows:

a. Cell tests with Pormax, nylon cloth and netting gave results that bracket the desirable features sought.

b. Saturated Pormax gave no electrolyte level effect on discharge and showed poor recombination properties on overcharge. Its fine pore structure presents surface forces too strong for gravity or gassing forces to overcome. It has a low value for the ratio of pore area to thickness.

c. The two nettings have relatively large apertures which are too great, as observed in drain tests, to support for long a film of electrolyte. The nettings gave pronounced discharge level effects but showed generally unfavorable cell voltages and pressures during sealed overcharge of partially drained elements. Note in Table V the low values of electrolyte retention.

d. Cells utilizing the 96 mesh non-filament nylon cloth, a very open-weave type, showed a small decrease in discharge capacity with decreasing electrolyte level <u>and</u> gave favorable bellows action and overcharge characteristics.

e. The Teflon screen, AGB 9-60-250, supports a height of liquid about half that of the 96 mesh cloth on the 2 minute vertical drain test. This data suggests a greater discharge capacity vs electrolyte effect with improved overcharge characteristics for the Teflon screen. This consideration, along with its practical thickness of 10 mils, clearly indicates the value of cell testing this material during next quarter's work.

f. The cell mechanism envisioned for the 67 mesh Teflon screen with its 9.8 mil aperture and 10 mil thickness is that of keeping the negative plate supplied with a constant thin film of electrolyte during drained overcharge.

g. Good drainage seems assured for the free electrolyte between the plates at the initial level drop and also for excess free electrolyte expelled by plate gassing. The thin film of electrolyte observed to be supported by the screen aperture is regarded as easily permeable by oxygen and, when broken by gassing, easily restored by freshly expelled electrolyte. Among the 67 mesh per inch, a significant number of spaces will be at all times bridged by electrolyte for ionic and dissolved oxygen transfer with the remaining mesh open for direct gaseous passage.

h. The chemical inertness and heat stability of Teflon are further assets. Cost is the chief disadvantage.

2.1.3 Bellows and Bellows Substitute Study. -

2.1.3.1 Bellows. - Detailed inquiries were sent to eight manufacturers of bellows with requirements for four different ranges of volume change: 20, 10, 4 and 2 cc. Uncertainty over the type and dimension of the separator to be used was the reason for specifying a range rather than an exact size. A 1" outside diameter was specified.

Five responses yielded only one bellows worthy of serious consideration. This one, from the Servometer Corporation, Clifton, N.J., offered the following advantages:

a. A reasonable price, including specified end fittings.

b. A reasonably short delivery.

c. The least extended bellows length.

d. The shortest compressed length.

e. An electroforming technique that can be used in the future for rectangular bellows (the material is pure nickel).

An order was placed for ten bellows, five of the 20 cc range and five of 10 cc range. Delivery has been promised by February 10, 1965.

2.1.3.2 <u>Bellows Substitute (Plastic Pillows)</u>. - The study of non-metallic bellows substitutes in the form of plastic pillows has covered a survey of twenty or more sources of supply for film, tubing, and bags. Appendix A lists some of these sources.

Techniques for heat sealing have included hot rolling, hot pressing and flame. Air in exact amount can be added to experimental pillows by hypodermic needle with re-seal of the puncture.

Heavy films and thick wall round tubing are unsuitable due to stiffness which inhibits flexing and which imparts an unfavorably large dead volume.

The thinner films such as polyethylene and nylon show excellent volume change characteristics but are subject to fatigue failure at points of severe flexing. Table VI lists some data gathered by automatic flex testing on ten sample pillows ranging from 4 mils to 20 mils thickness of basic material. The specimens were all flex tested while immersed in 25% KOH electrolyte at room temperature. Some excellent values of both $\Delta V/V$ and flex life have been obtained, but the relatively isolated successful results should be repeated at low temperature before an accurate assessment can be made of cycle life. A goal of 10,000 cycles in the temperature range of 0°C to 50°C has been selected as a contract objective.

Samples of laminates polyethylene and polypropylene to Mylar are being procured to improve gas retention properties. Saran as a laminate (4) and Kel-F tubing alone (5) (6) are reported to have excellent gas impermeability.

The possibility of an effective and reliable plastic bellows device continues to warrant an active investigation.

2.1.4 Six Ampere Hour Test Cells. - Fifteen clear lucite containers with a bellows chamber have been constructed essentially as shown in Figure 8.

To keep the free electrolyte volume to be handled by bellows action at a minimum, the clearance between element (plate pack) and jar walls has been reduced to a minimum. Plastic shims will be used to achieve this fit in the plate thickness direction.

A cylindrical plastic bellows chamber was adopted to permit a clear view of bellows action either while attached to the cell or separately during bellows evaluation tests. An "O"-ring seal permits easy attachment or removal of the chamber from the cell bottom. The threaded end cap with "O"-ring seal permits installation or replacement of the bellows. A tapped hole in this cap can be used to pre-charge the bellows by air pressure or evacuation. It can be plugged should a fully encapsulated device such as a plastic pillow or sealed bellows be used. This access cap also permits addition of shims to lessen the liquid volume or limit the extension of a bellows.

The removeable feature of the cylindrical chamber makes possible the eventual addition of a permanent prismatic bellows chamber below or at the side to achieve a relatively practical overall cell configuration.

Provision is made in the cell top, between the posts, for a 1/8" pipe assembly of pressure gauge and needle valve. In one narrow cell wall, near the top and above the plates, is the location for a pressure relief valve set at 90 PSIG.

The active material content of all the sintered positive and negative plates was recorded during their impregnation. Using this record, the positive and negative plate groups were selectively composed to provide uniformity of capacity among the fifteen test cells. All plate groups are ready for final assembly.

In order to determine the amount of electrolyte drainage to expect from a tightly assembled 6 AH element, three cells were assembled with three different separator materials, DuPont Vexar netting, Nalle "Rice Bag" netting and AGB8-M double layer nylon cloth. The results of calibration tests to relate electrolyte level and electrolyte volume are plotted in Figure 9. Note that the nylon cloth separated cell can be flooded with less than half the volume of electrolyte needed to flood the cells with net separators, as predicted by the test data of Table V.

2.2 Task 2 - Feasibility of Bellows Controlled Electrolyte Level In Sealed Cd/KOH/AgO and Zn/KOH/AgO. - Work on this task was delayed until the optimum bellows could be established by the work described in 2.1.3.

3. NEW TECHNOLOGY

No new technology was introduced into the program during the second quarter.

4. PROGRAM FOR NEXT QUARTER

4.1 Task 1. - Task 1 will be completed by the testing of fifteen 6-ampere hour Ni-Cd sealed test cells designed according to the factors given in Table VII. Tests programmed are given in Table

VIII. The ratio of charged active materials will be evaluated for effect on recombination during overcharge.

4.2 Task 2. - Design and fabricate six 12-ampere hour sealed Ag-Cd test cells with oxygen electrodes and a non-cellulosic, micro-porous, rapid draining separator system to promote efficient bellows action and rapid recombination.

4.3 Task 3. - Select, procure, and install a pressure sensitive microswitch in a metal bellows and evaluate in a bellows cell. As a design goal, develop a similar switch actuated by cell pressure and exposed to the alkaline environmental for use in pillow equipped cells.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Control of electrolyte level in sealed 4.0 AH sintered plate Ni-Cd cells by partially inflated plastic pillows has been demonstrated in a 22/2 hour orbit at a 70% depth of discharge and in a 90/30 minute orbit at a 70% depth of discharge at 25°C.

5.2 An electrolyte of 20% KOH offers the best compromise between discharge capacity and rapid drainage requirements for optimizing the performance of a cell with a "pillow-controlled" electrolyte level.

5.3 An open weave nylon cloth combined with 20% KOH provides the optimum compromise between discharge capability and overcharge requirements of the microporous, netting, non-woven, and woven separator materials tested to date.

5.4 Accelerated cycling tests consisting of rapid expansion and compression of rectangular pillow style plastic bellows have given a maximum cycle life of 25,000 cycles when performed in 25% KOH electrolyte. A principal mode of failure has been fatigue failure at flex points near the heat seal.

5.5 Metal cylindrical bellows with competitive values of $\Delta V/V$ volume efficiency and greater durability have been procured for tests in the next quarter.

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(3) Final Report, Contract NAS5-1045, R. & D. Program on Sealed Ni-Cd Cells for Space Use, April 30, 1963.

(4) Modern Packaging, Encyclopedia Issue, 1964, Page 244, Vacuum and Gas Packaging.

(5) Quarterly Report No. 2, Contract NAS3-4168, Development of The Dry Tape Battery Concept, 16 September 1964, Page 37, Table 13, Permeability to Gas and Water Vapor of Encapsulation Films.

(6) James M. Rice, Silver-Cadmium Battery Development Program, Contract NAS5-1431, NASA CR-85, Table X, Page 31, September 1964.

APPENDIX A

PILLOW MATERIALS AND SOURCES OF SUPPLY

1. Broli Autoclavable Nylon Tubing (100' X 1-1/2" X 0.002") (made in Sweden) (Diversified Products Nylon Autoclavable Film No. 1041).

2. Stokes Molded Products Division, E.S.B., Trenton, N.J.

Flat Tubing:	Vinyl	(1-5/16" wide X .017" thick)
Flat Tubing:	Polyallomer	(1-1/16" wide X .014" thick)
Flat Tubing:	Polyethylene	(1" wide X .016" thick)

3. Westlake Plastics Company, Lenni Mills, Pa. "Ethylux" sheeting in 10, 15 and 20 mil thickness Standard Pillow Floats.

4. General Chemical Division of Allied Chemical Corporation, Morristown, N.J. "ACLAR" fluorohalocarbon film. R. F. sealed poucher of 9 mil Aclar, 22A.

5. Ivers-Lee Company, Newark, N.J. "3-DEE" packages combination 1L-d1-LEK 21 (Allied Chemical "ACLAR") (6 mils thick) (a fluorohalocarbon), 1L-D-6 (Minnesota Mining & Mfg. Co. "Scotchpak").

6. General Chemical Division, Allied Chemical Corporation, Charlotte, N. C. Capran (polyamide) film thickness = 3 mils.

7. Avisun Corporation, Philadelphia, Pa. Olefane A-25, polypropylene film, 4 mils thick, one side corona discharge treated for printability (Spec. 1000, EPO 387, No. (1-5632) also, untreated film.

8. Sealed Air Corporation, Hawthorne, N.J. "Aircap" small air filled capsules of thin Saran and polyethylene film.

9. Extron Corporation, Knoxville, Tenn. "Transtube" Flexible, clear, PVC tubing I.D. = 1/2, 3/4 and 1". Local distributor: Robert E. Mason & Associates, Inc., Charlotte, N. C.

10. Continental Can Co.

    Laminate of 1.5 mil polypropylene on 0.5 mil Mylar
    Laminate of 3 mil polyethylene on 0.75 mil Mylar.
    Laminate of 1.5 mil medium density polyethylene on 0.5 mil Mylar.

11. The United States Stoneware Company, Akron, Ohio Tygon Flexible Plastic Tubing, Formulation R-3603, 1" I.D., 1-1/4" O.D., 1/8" wall 1/2 I.D., 5/8 O.D., 1/16".

12. Commercial Plastics and Supply Corporation, Atlanta, Ga. "Astra/08" extruded flexible tubing 3/4 I.D X 35 mil wall (Decomposed by KOH) Polyethylene sheet "Boronol" Type A, 20, 30, 60 and 90 mils thick.

13. E. I. DuPont de Nemours and Company, Inc. "Surlyn A" thermoplastic. (Sheet or tube samples requested) (none received).

14. Shop Stock - Polyethylene sheet, 4 mils.

15. Adam Spence Corporation, Union, N.J. - KEL-F-81 tubing (used by J. A. Deknatel & Son, Inc., Queen Village, Long Island, N.Y. as a suture package).

FIGURE 1

VARIATION OF
CELL PRESSURE AND BELLOWS CONTROLLED ELECTROLYTE LEVEL
DURING 24-HOUR ORBIT CYCLING
OF 4 AH Ni-Cd SEALED CELLS

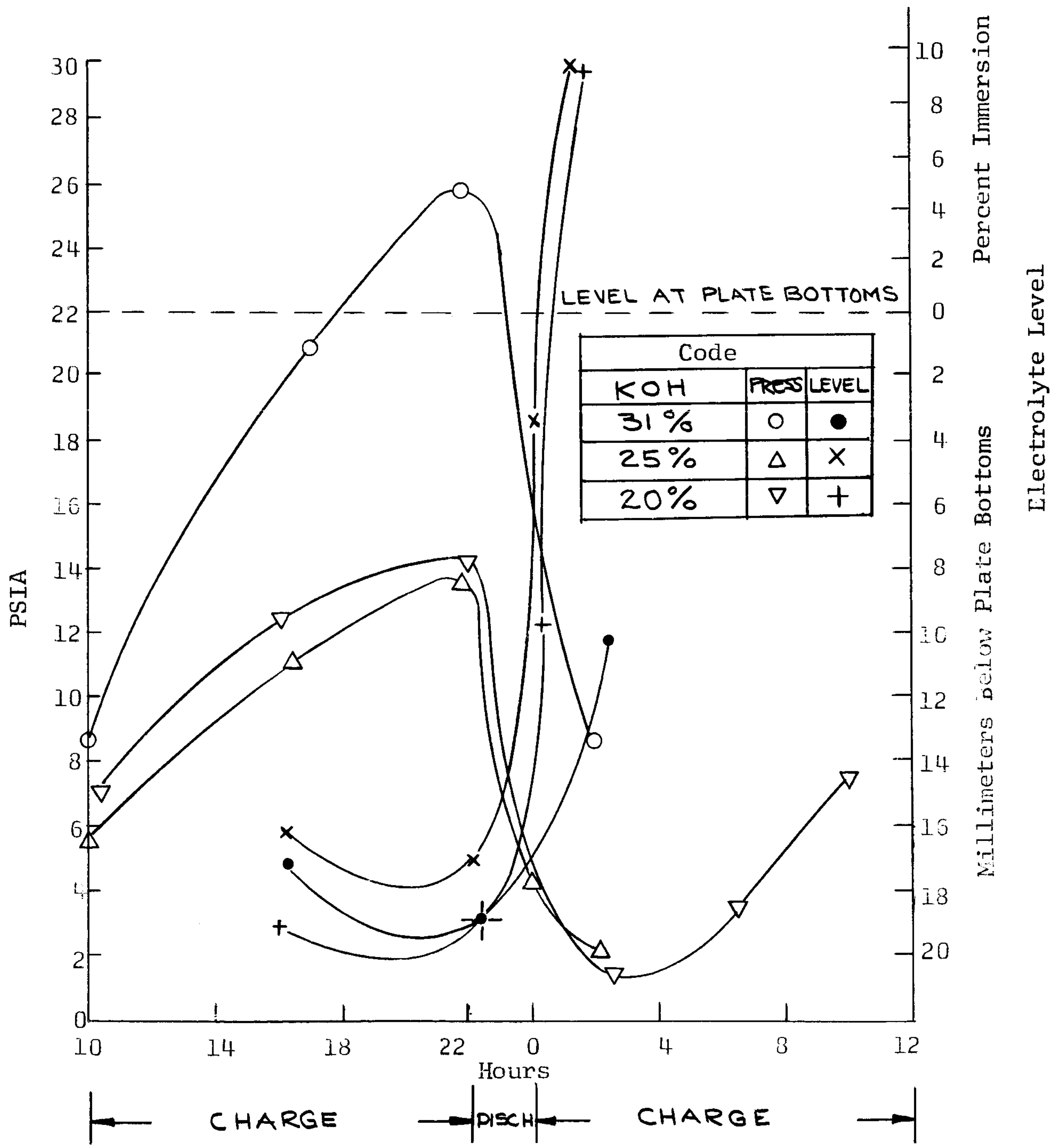


FIGURE 2
VARIATION OF CELL PRESSURE AND BELLOWS CONTROLLED ELECTROLYTE LEVEL
DURING 2-HOUR ORBIT CYCLING OF 4 AH NiCd SEALED CELLS: CYCLES 1-4

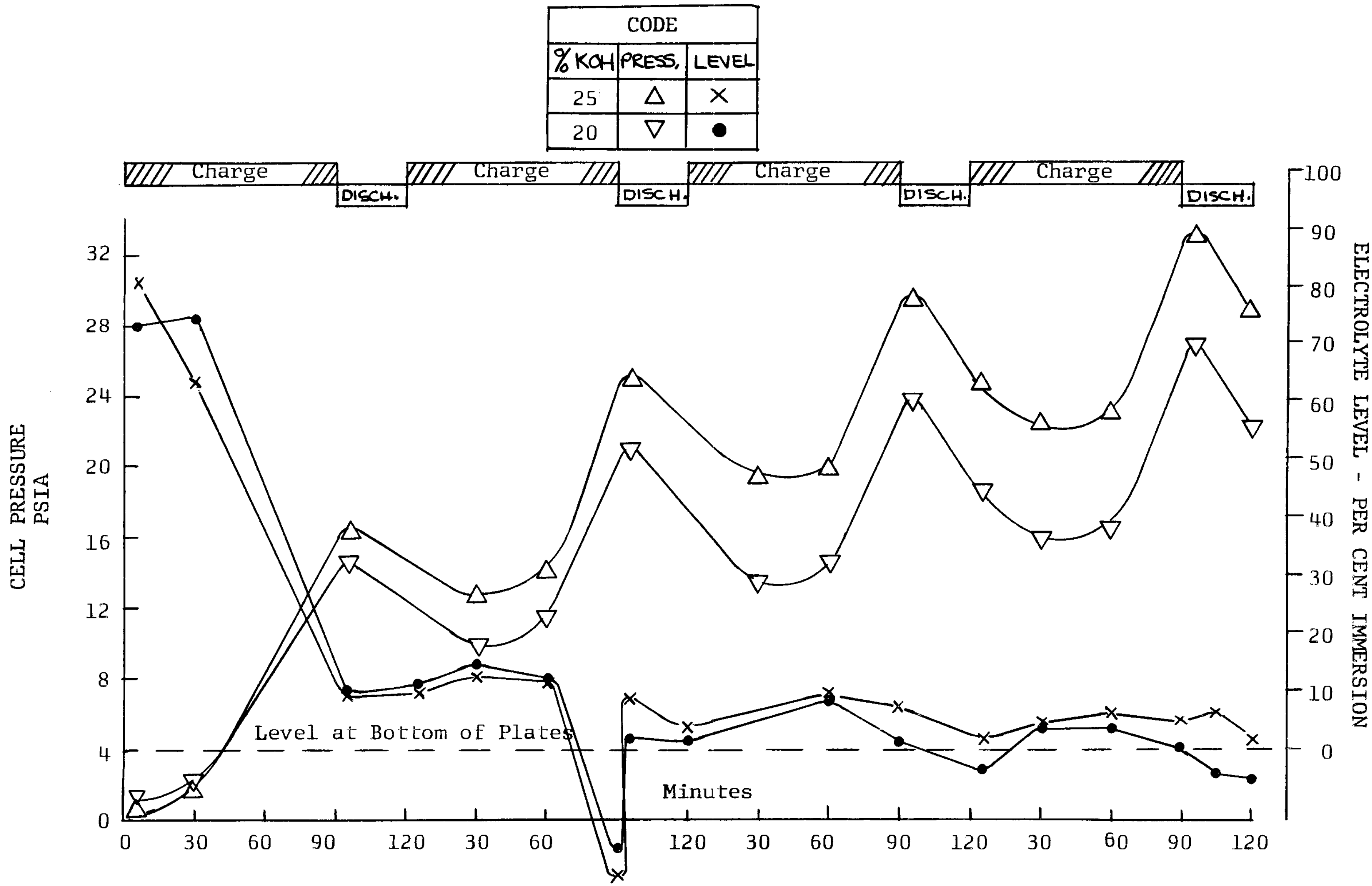
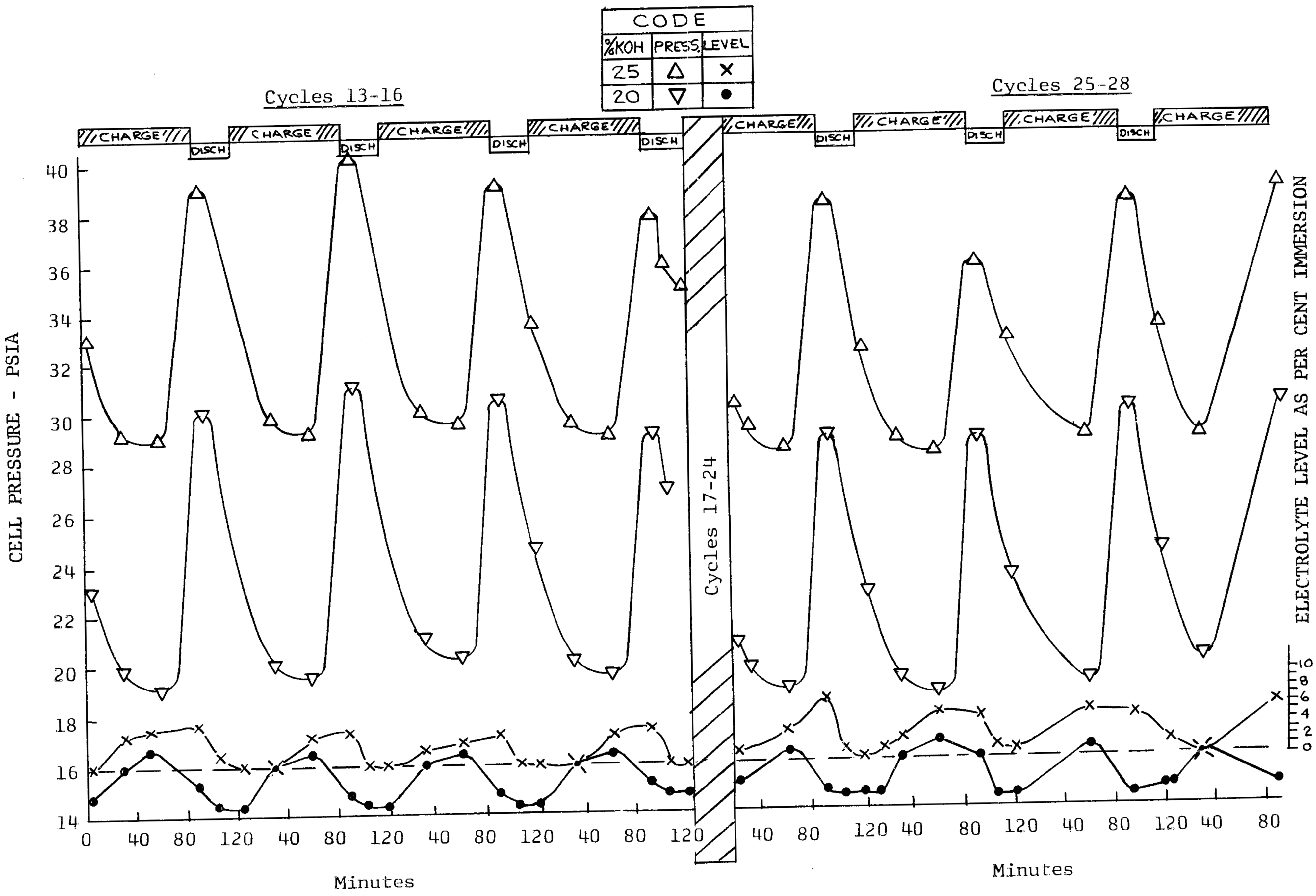


FIGURE 3
VARIATION OF CELL PRESSURE AND BELLOWS CONTROLLED ELECTROLYTE LEVEL
DURING 2-HOUR ORBIT CYCLING OF 4 AH NiCd SEALED CELLS: CYCLES 13-28



25% KOH	20% KOH	Explanation
△	▽	Pressure
▲	▼	Press at re-evac. to check pillow response
×	•	Electrolyte level
⊠	⊡	Electrolyte level at re-evac. after test
⊗	⊙	Electrolyte level before test

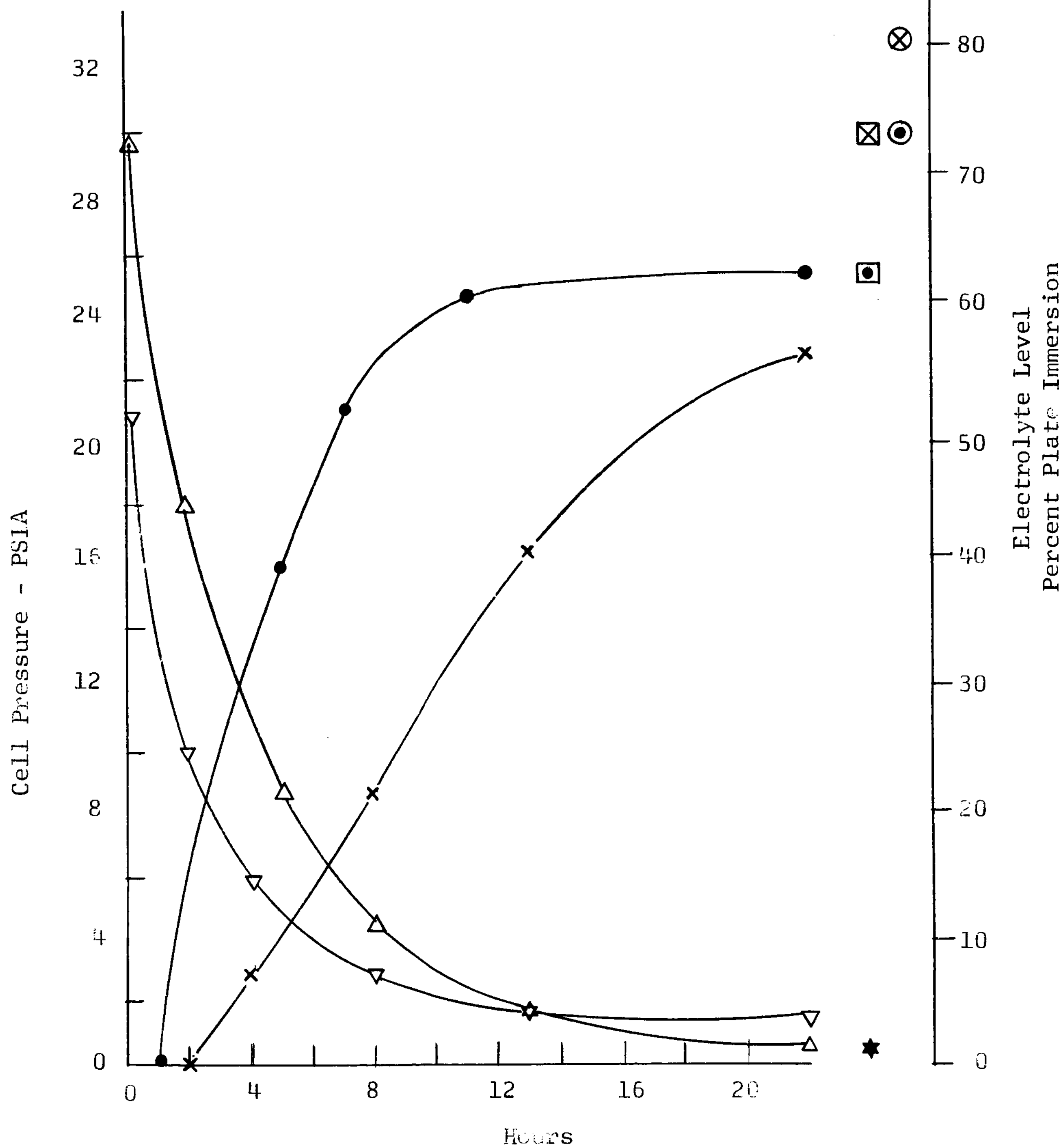


FIGURE 4
VARIATION OF CELL PRESSURE AND BELLOWS CONTROLLED ELECTROLYTE LEVEL ON OPEN-CIRCUIT STAND AFTER 2-HOUR ORBIT CYCLING

FIGURE 5
EFFECT OF OPEN WEAVE SEPARATOR MATERIALS ON DISCHARGE CAPACITY OF 4 AH Ni-Cd CELLS WITH 10%, 50% AND 100% PLATE IMMERSION IN CELL ELECTROLYTE

CODE		
IMMERSION LEVEL	25% KOH	20% KOH
100%	○	◯
50%	△	▽
10%	□	◊

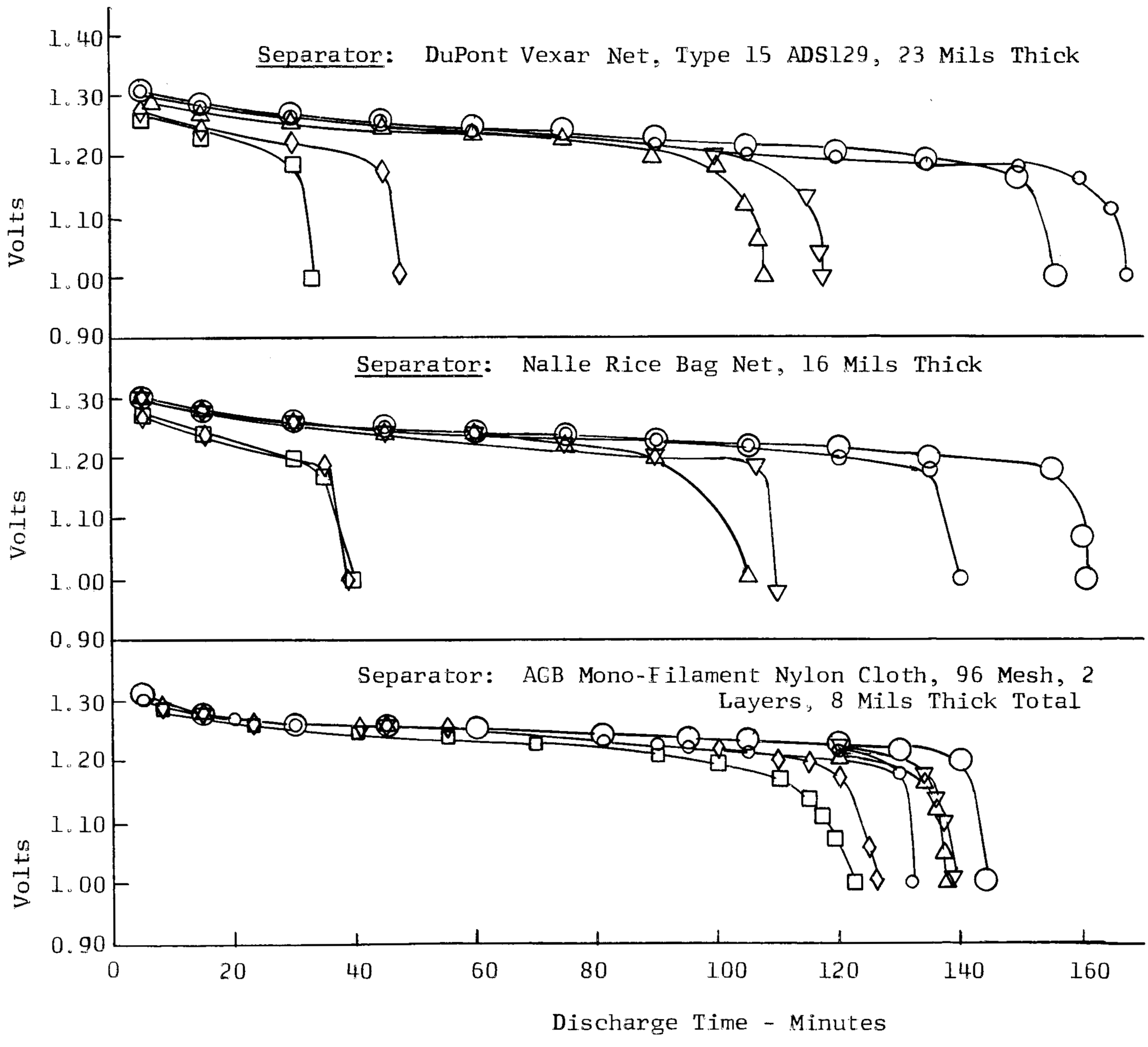


FIGURE 6
EFFECT OF OPEN WEAVE SEPARATOR MATERIALS ON CHARGE AND OVERCHARGE VOLTAGE, PRESSURE AND BELLOWS CONTROLLED ELECTROLYTE LEVEL IN 4 AH Ni-Cd CELLS WITH 25% KOH

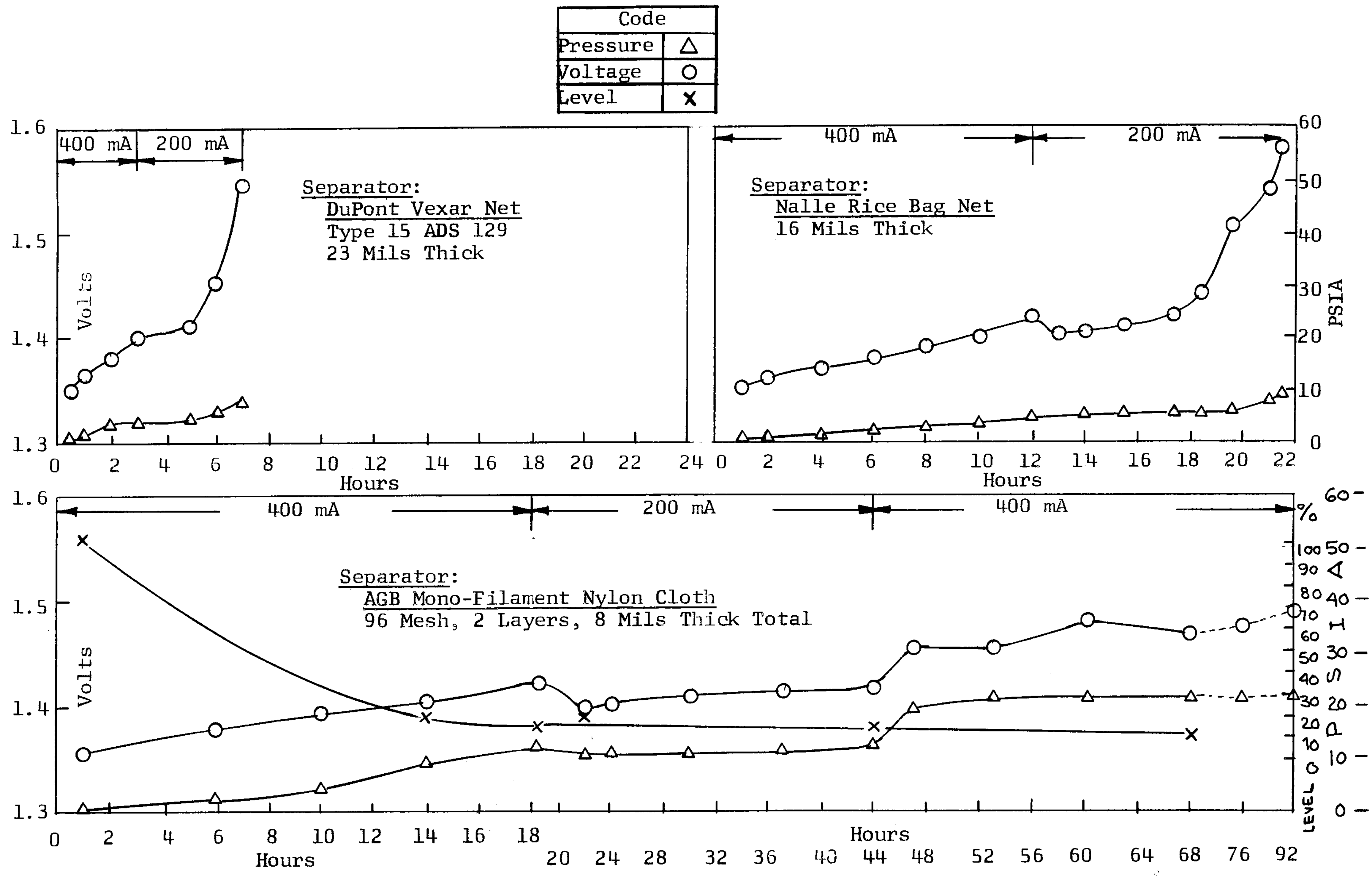
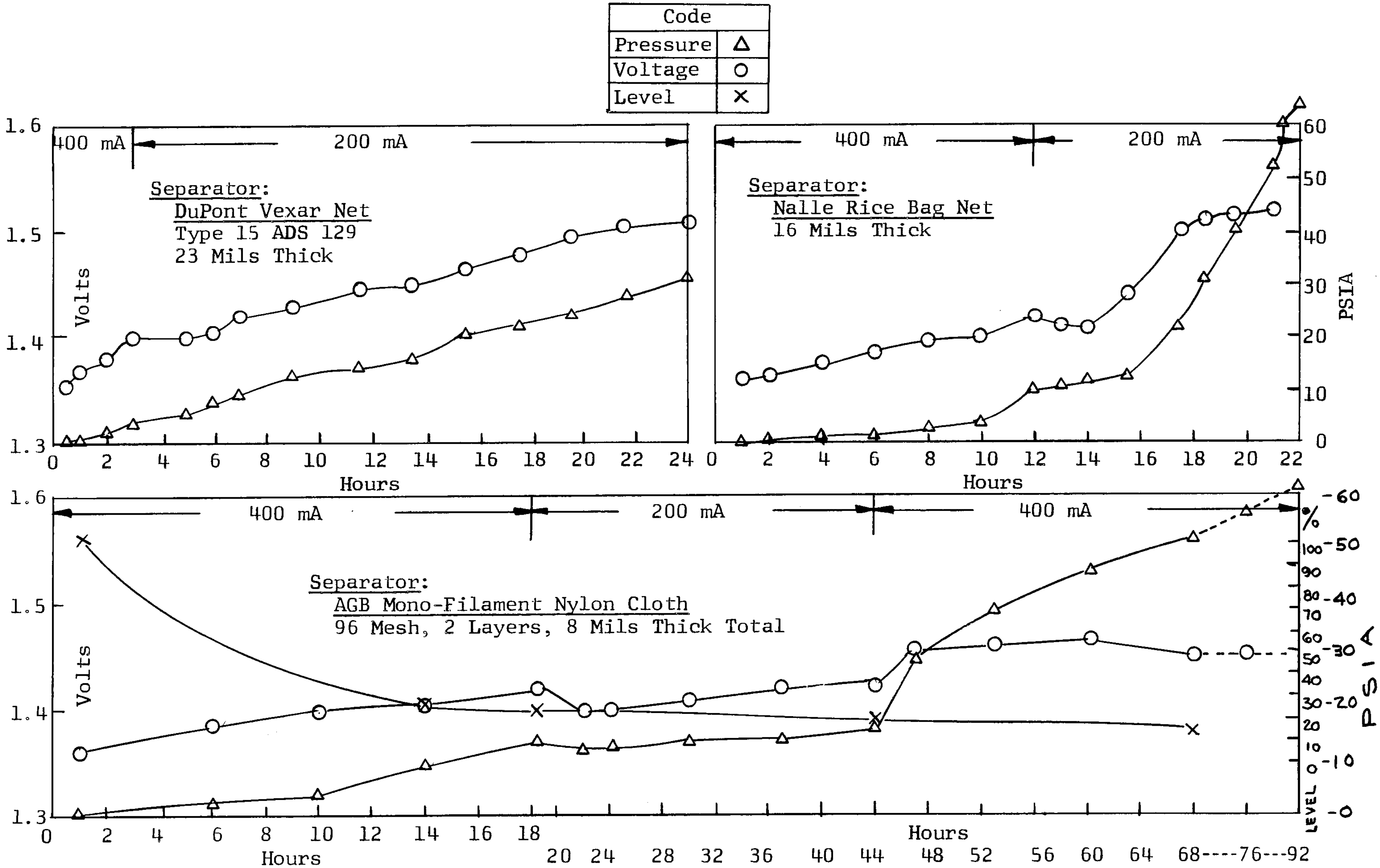


FIGURE 7
EFFECT OF OPEN WEAVE SEPARATOR MATERIALS ON CHARGE AND OVERCHARGE VOLTAGE, PRESSURE AND BELLOWS CONTROLLED ELECTROLYTE LEVEL IN 4 AH Ni-Cd CELLS WITH 20% KOH



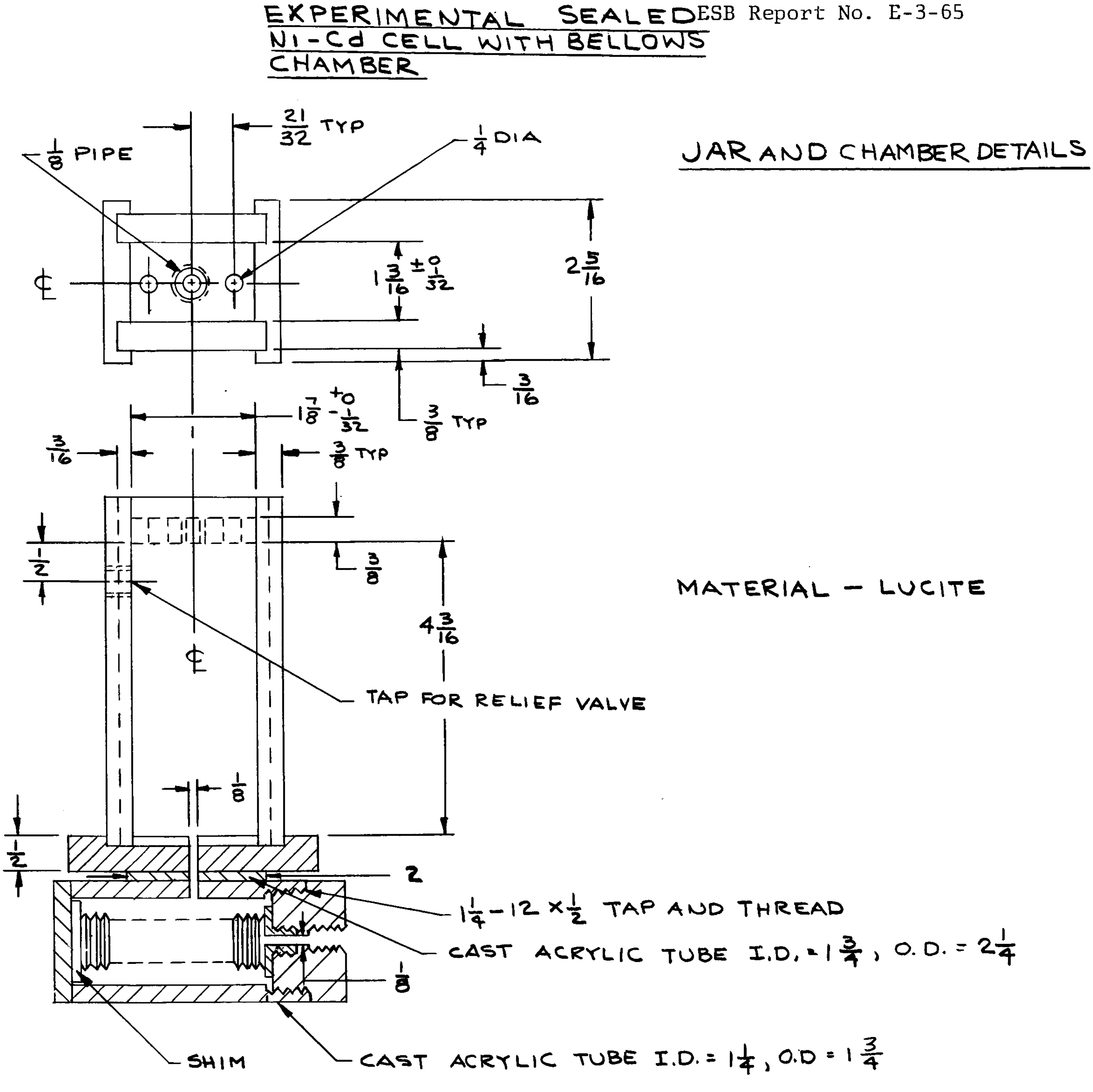


FIGURE 8

EXPERIMENTAL SEALED Ni-Cd CELL WITH BELLOWS CHAMBER

FIGURE 9
EFFECT OF OPEN WEAVE SEPARATOR MATERIALS
ON RELATION BETWEEN ELECTROLYTE LEVEL AND ELECTROLYTE
VOLUME IN 6 AH Ni-Cd CELL

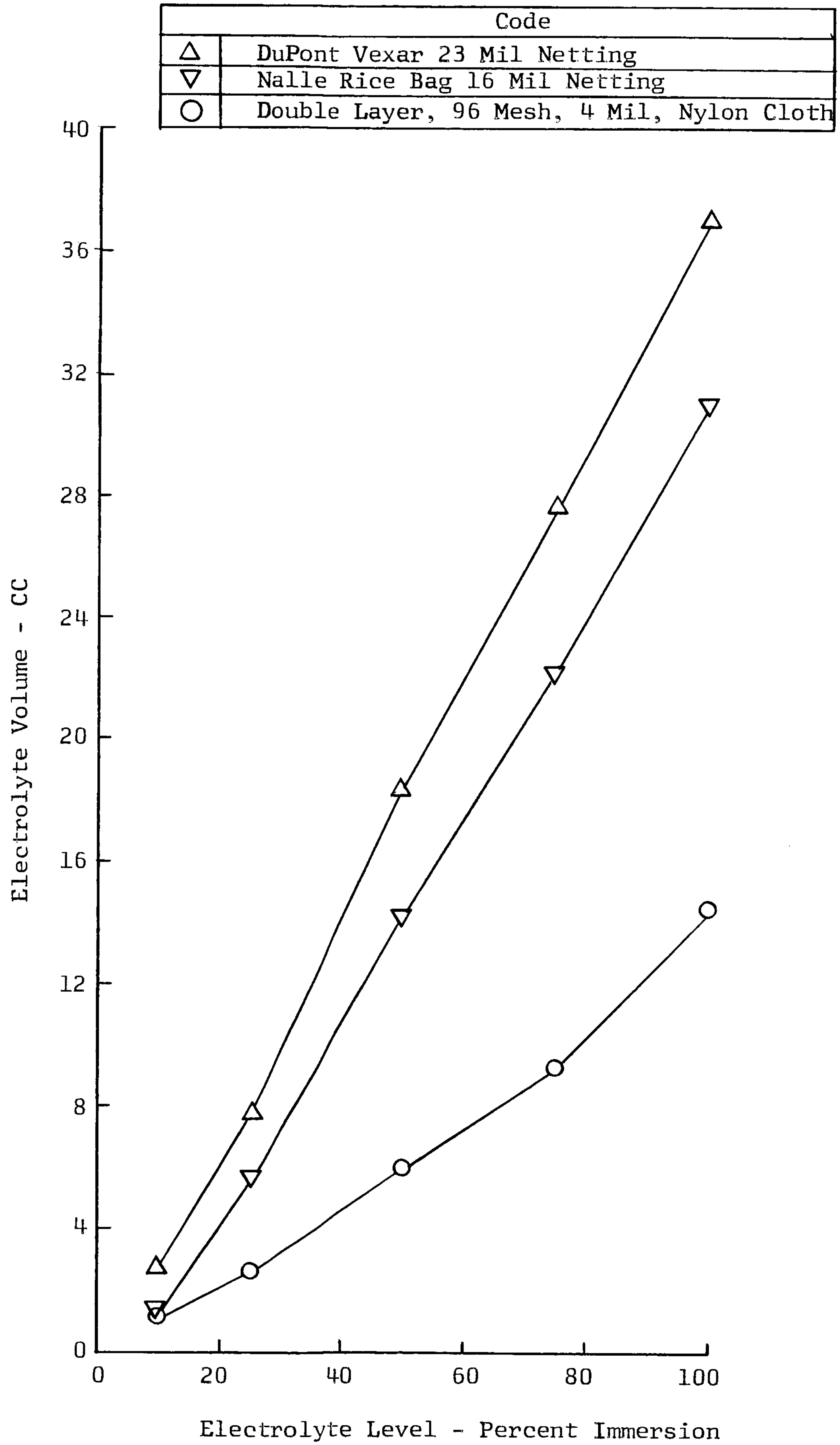


TABLE I

EXPERIMENTAL 4.0 AH NiCd CELL TESTS TO OBTAIN OPTIMUM BELLOWS CONTROLLED RECOMBINATION CONDITIONS

Series Code	Electrolyte Concentration KOH (%)	Plate Immersion Under Vacuum (%)	Separator Type (*)	Bellows Type	Cycling Charge/ Discharge Times	Charge Rate (Amps)	Charge Input (AH)	Disch. Rate (Amps)	Disch. Output (AH)	Number Cycles In Test
All Runs	20,25,31	10,52,72, 100	Screen Cloth Netting	Pillows	22/2 Hrs. 90/30 Min.	0.06C- 0.93C	1.1- 1.4C	0.35C- 1.4C	0.7C to 1.0C	5-24 Hr. 53-2 Hr.
D-1-1 D-1-2	25 31	10	Nylon Screen A	Pillow A	22/2	C/16	1.37C	0.35C	0.70C	5
D-2-1 D-2-2	25 20	10	Nylon Screen A	Pillow A	22/2	C/16	1.37C	0.35C	0.70C	6
D-3-1 D-3-2	25 20	10	Nylon Screen A	Pillow A	90/30	0.93C	1.4C	1.4C	0.70C	2
D-3-3 D-3-4	25 20	10	Nylon Screen A	Pillow A	90/30	0.65C	0.98C	1.4C	0.70C	4
D-3-5 D-3-6	25 20	10	Nylon Screen A	Pillow A	90/30	0.51C	0.77C	1.4C	0.70C	11
E-1 E-2	25 20	72	Nylon Screen A	Pillow A	90/30	0.51C	0.77C	1.4C	0.70C	37
H-1 H-2	25 20	100	Polyethylene Netting H	Pillow A	16/2	0.10C	1.6C	0.5C	1.0C	3
I-1 I-2	25 20	100	Netting C	Pillow A	16/2	0.10C	1.6C	0.5C	1.0C	3
J-1 J-2	25 20	100	Nylon Cloth D	Pillow A	16/2	0.10C	1.6C	0.5C	1.0C	3

(*) Separators: Type A Nylon screen, 4 mils thick mono-filament, 120 X 120 mesh, 2 layers.
B DuPont Vexar, type 15ADS 129, 23 mils thick, polyethylene, 1 layer (Netting).
C Nalle Plastics Co., "Rice Bag" netting, 16 mils thick, 1 layer.
D A.G.B. type 8M nylon screen, 4 mils thick, 96 X 96 mesh, 2 layers.

TABLE II

CELL PRESSURE AND ELECTROLYTE LEVEL EXTREMES DURING 24-HOUR ORBIT CYCLING TEST OF 4 AH NiCd CELLS

Cycle No.	Maximum Pressure State				Minimum Pressure State				
	Occurrence		Cell Pressure-Abs. Atm. and KOH %		Occurrence After Charge	Cell Pressure-Abs Atm. and KOH %		Plate (4) Immersion-%	
	D Min.	C Hrs.	25	31	Hrs.	25	31	25	31
1	(1) 3		0.73	1.10	0 (2)	.07	.07	10.0	10.0
2	5		1.00	1.78	2.0	.17	.43	8.5	11.6
3		21.5	1.20	1.82	1.8	.20	.60	11.0	12.2
			25	20		25	20	25	20
6		21.7	1.48		0 (3)	.07		10.0	
1				0.85			.07		10.0
7		22.0	1.58		0.6	.60		0	0
2				1.00			.27		
8		20.0	1.44		4.1	.33		0	
3				1.07			.17		1.8
11		22.0	1.93		2.8	.37		6.1	
0				1.28			.20		9.8

Notes:

1. D = discharge C = charge. Maximum pressure occurred after 3 minutes of discharge.

2. Starting condition for test on cells S/N 3 (25%) and S/N 4 (31% KOH).

3. Starting condition for test on cells S/N 3 (25%) and S/N 4A (20% KOH).

4. Electrolyte level adjusted initially to 10% immersion. Maximum and minimum levels controlled by pillow bellows device. Minimum level at maximum pressure state varied from 16-21 mm below bottoms of plates.

5. Separator: Two layers 4 mil nylon mono-filament cloth.

TABLE III

CELL PRESSURE AND ELECTROLYTE LEVEL EXTREMES DURING 2-HOUR ORBIT CYCLING TESTS OF 4 AH NiCd CELLS

Cycle No. &	Cell S/N	Maximum Pressure State					Minimum Pressure State					
		Occurrence			Cell Pressure		Occurrence		Cell Pressure		Plate (2) Immersion	
		C	D	Chg. Rate	Abs. Atm.		C	D	Abs. Atm.			
3	4	Min.	Min.	Amps.	(KOH) %		Min.	Min.	(KOH) %		(KOH) %	
					25	20			25	20	25	20
12		89.5		0.93C	3.9			30	2.9		0	
	7	89.5		(3)		6.7		30		5.4		0
13		85.0		0.93C	5.7			30	4.1		0	
	8	85.0		(3)		6.8		30		5.4		0
14		90.0		0.65C	2.9			30	2.2		0	
	9	90.0		(3)		1.0		30		0.8		0
15		89.0		0.65C	2.5		30		1.6		0	
	10	89.0		(3)		1.3	30			0.6		0
18		90.0		0.51C	0.8		30		-		7.3	
	13	90.0		(3)		0.6	30			-		11.0
19			5.0	0.51C	1.4		30		0.64		0	
	14	90.0		(3)		1.4	30			0.43		0
20			5.0	0.51C	1.6		16		0.83		0	
	15		5.0	(3)		1.4	30			0.70		0
28			5.0	0.51C	1.2		-		-		-	
	23		5.0	(3)		1.0	-			-		-
29			5.0	0.51C	1.3		30		0.80		0	
	24		5.0			1.1	30			0.63		0

Notes: (1) Separator: 2 layers, 4 mil, 120 mesh nylon mono-filament cloth.
(2) Electrolyte Level: Initially 10.0% immersion at 26" vac. (0.13 abs. atm).
(3) Cycle Conditions: Charge 90.0 minutes at indicated rates to 1.4C, 1.0C, or 0.77C input.
Discharge 30.0 minutes at 5.6 amps (70% depth).

TABLE IV

CHARGE AND DISCHARGE CHARACTERISTICS OF 4 AH NiCd CELLS WITH NETTING AND WOVEN CLOTH SEPARATOR MATERIALS

Test Parameter	Separator System					
Separator Material	DuPont Vexar Net (23 Mils)		Nalle Net (16 Mils)		A.G.B. Nylon Cloth (8 Mils)	
Electrolyte Concentration, %	25	20	25	20	25	20
A. Open Cell Discharge Tests: (1) (2)						
1. Flooded Cell Capacity, A.H. 100% Plate Immersion	5.58	5.20	4.66	5.36	4.40	4.80
2. Cell Capacity, A.H. 50% Plate Immersion	3.60	3.90	3.50	3.64	4.58	4.62
Capacity, % Flooded Capacity	65	75	75	68	104	96
3. Cell Capacity, A.H. 10% Plate Immersion	1.10	1.58	1.32	1.30	4.08	4.02
Capacity, % Flooded Capacity	20	30	28	24	93	88
B. Sealed Cell Charge Tests:						
1. Charge and Overcharge						
Input at C/10 rate, AH	1.2	1.2	4.90	4.90	7.3	7.3
Input at C/20 rate, AH	0.8	4.2	1.80	1.99	5.1	5.1
Second Input at C/10 rate, AH	---	---	---	---	19.2	19.2
Total Input, AH	2.0	5.4	6.7	6.89	31.6	31.6
2. Test End Voltage, Volts	1.545	1.51	1.54	1.51	1.49	1.45
3. Maximum Cell Pressure, Abs. Atm.	0.53	2.9	0.57	4.4	1.5	4.2
4. Plate Immersion, % at Test End (3)	26	16	40	27	10	15

Notes: (1) Each charge 16 hours at C/10 rate = 6.4 AH input.
(2) Each discharge at C/2 rate to 1.00 volt per cell.
(3) Initially plates were 100% immersed.

TABLE V

PHYSICAL CHARACTERISTICS OF NETTING TYPE SEPARATORS

Separator Material	Thickness δ Mils	Mesh L Mils	Size W Mils	Mesh Opening Area Per In^2 Material A $Mils^2 \times 10^4$	Ratio $\frac{A}{\delta}$ $\times 10^4$	Electrolyte Absorption $Mg/in^2/Mil$	Electrolyte Retention After 2 Min. Simple Drain $cc/in^2 \times 10^{-2}$	Plate Immersion After 2 Mins. Simple Drain (%)
Teflon screen AGB 9-200-74	8	2.9	2.9	24.3	3.04	4	9.4	98
Nylon mono-filament Cloth AGB 120 mesh	7	5.4	5.4	41.0	5.85	8	11.5	100
Same 96 Mesh	8	6.3	6.3	36.6	4.57	12	10.2	98
Teflon screen AGB 9-60-250	10	9.8	9.8	43.1	4.31	6	--	43
Teflon screen AGB 9-45-350	16	13.7	13.7	38.6	2.41	8	--	28
Teflon screen AGB 9-40-420	23	16.5	16.5	37.3	1.62	1.2	9.5	30
Teflon screen AGB 9-18-1000	30	39.4	39.4	50.3	1.68	0.12	9.5	18
Nalle "Rice Bag" Netting	16	105 L	75 8	52.4	3.28	1.9	7.6 long axis 8.2 short axis	18
DuPont Vexar 15 ADS 129 netting	23	90 L	55 S	25.7	1.12	1.2	8.2 long axis 8.4 short axis	18

δ = Thickness of the diffusion layer
L = Long axis of diamond
S = Short axis of diamond

TABLE VI

AUTOMATIC FLEXING TEST ON PILLOW TYPE BELLOWS SUBSTITUTES
IMMERSED IN 25% KOH ELECTROLYTE
AT ROOM TEMPERATURE

Flex Cycle: 11 Seconds Evacuation to 28"
1 Second Exhaust

Pillow Material	Dimensions Inside Seal	Sealing Method	Displacement Under Water: Volume Empty (cc)	Displacement Under Water: Volume With Air At Patm. (cc)	Displacement Under Water: With Air Under Vac 28" Hg (cc)	Volume Change ($V_{vac}-V_{atm}$) = ΔV (cc)	$\frac{\Delta V}{V_{Vac}}$	Flexing Cycles To Failure
Polyethylene Sheet, 4 mil, Double Layer	1 3/4 X 1 7/8	Flame	1.5	2.75	14.0	11.25	0.805	297 (1)
Polyethylene Sheet, 4 mil, Double Layer	1 3/4 X 1 7/8	Hot Wheel	2.0	3.0	14.0	11.0	0.785	79 (1)
Polyethylene Sheet, 4 mil, Single Layer	1 3/4 X 1 7/8	Hot Wheel	1.0	2.0	17.0	15.0	0.882	20 (2)
Swedish Nylon Autoclave Tubing, 2 Mils, Single Layer	1 15/16 X 1 1/2	Flame	0.25	1.5	16.0	14.5	0.905	700+ (3)
Capran (Polyamide) Film, 2 mils, Single Layer	1 3/4 X 1 7/8	Flame	0.5	1.75	15.0	13.25	0.884	7000 (1)
Polypropylene Film, 3.5 Mils, Single Layer	2 X 1 7/8	Hot Wheel	1.4	2.0	12.5	10.5	0.84	6000+ (4)
Capran, 2 mils, Single Layer, Inside Polyethylene, 4 mils, Single Layer	1 3/4 X 1 3/4 / 1 15/16 X 1 7/8	Flame / Hot Wheel	0.75	2.25	18.0	15.75	0.875	670 (1)
Stokes, Polyallomer, Flat Tube, 14 Mils	1 1/16 X 1 3/4	Hot Press	2.0	2.0	4.0	2.0	0.50	+25,000 (4)
Stokes, Polyethylene, Flat Tube, 16 Mils	1 X 1 3/4	Hot Press	1.5	2.5	4.0	1.5	0.374	+6,000 (1)
Stokes, Vinyl, Flat Tube, 17 mils	1 5/16 X 1 3/4	Hot Press	2.0	2.5	6.0	3.5	0.584	49,000 (4)
Polyethylene Sheet, 20 mils, Single Layer	1 1/2 X 1 7/8	Hot Press	2.5	3.25	6.0	2.75	0.458	715 (2)
Polyethylene Sheet, 20 mils, Single Layer	1 3/4 X 1 7/8	Hot Press	3.5	5.0	6.0	1.0	0.17	320

TABLE VI

AUTOMATIC FLEXING TEST ON PILLOW TYPE BELLOWS SUBSTITUTES
IMMERSED IN 25% KOH ELECTROLYTE
AT ROOM TEMPERATURE
(Continued)

(1) Failure due to fatigue crack at boundry of heat seal and free film.

(2) Failure due to poor heat seal, high expansion caused extreme flexing.

(3) Failure at crease points on original folded edges.

(4) No failure. Test stopped at indicated cycle life.

TABLE VII

DESIGN FACTORS FOR
15-6 AMPERE HOUR Cd/KOH/NiOOH SINTERED PLATE TEST CELLS
FOR EVALUATION OF BELLOWS ACTION

PLATES

Positive - 6 plates @ 1-3/4 X 1-3/4 X 0.050"
Negative - 7 plates @ 1-3/4 X 1-3/4 X 0.050"

SEPARATOR*

Type 1 - AGB 8-M Nylon mono-filament screen cloth, double layer, 8 mils total thickness.
Type 2 - AGB 9-60-250 Teflon mono-filament screen, 1 layer, 10 mils.
Control 3 - Pormax, microporous PVC sheet, 10 mils.

ELECTROLYTE
20% KOH

LEVEL CONTROL

3 cycles, flooded, with two electrolyte re-newals

PRE-SEAL GROUP CHARGE ADJUSTMENT

To give sealed ratio: Chg'd neg./Chg'd pos. cap. = 1.4

(*) Separator Assignment to Cell Groups

INITIAL TEST GROUP (6 Cells)

Cell Nos. 1, 2, 3 = nylon cloth separators
Cell Nos. 5, 6, 7 = Teflon screen separators

CONTROL GROUP (3 Cells)

Cell No. 4 = Nylon
Cell No. 8 = Teflon
Cell No. 9 = Pormax

OPTIMIZED GROUP (6 Cells)

Cell Nos. 10 through 15 = Pormax initially for 3 cycle formation.
Cell Nos. 10 through 15 = best material based on initial tests.

TABLE VIII

EVALUATION TEST SCHEDULE
FOR 6 AMPERE-HOUR BELLOWS CONTROLLED
Cd/KOH/NiOOH CELLS

<table>
<tr><th>Step</th><th>Test Description</th><th>Test Cell Description And Assignment</th></tr>
<tr><td>1</td><td>BELLOWS CALIBRATION
1.1 Compression Stroke Test
1.2 Expansion Stroke Test
1.3 Composite Stroke Test</td><td>All metallic bellows and pillows as indicated</td></tr>
<tr><td>2</td><td>MANUAL BASELINE TESTS</td><td>Initial Test Group:</td></tr>
<tr><td>2.1</td><td>Open Cell Discharge Capacity
Rates = C/5, C/2, C/1
Temperatures = 0°C and 25°C
Electrolyte Levels = 100%, 50%, 10%
Control Group = Force Drained</td><td>Cells 1, 2, 3, Nylon cloth sep's.
Cells 5, 6, 7, Teflon screen sep's.
Sealed Cell Control Group:
Cell No. 4 nylon cloth sep's.
Cell No. 8 Teflon screen sep's.
Cell No. 9 Pormax sep's.</td></tr>
<tr><td>2.2</td><td>SEALED CELL OVERCHARGE CAPABILITY
Rates = C/20, C/10, C/5, C/2
Temperatures = 0°C and 25°C
Electrolyte Levels = 50%, 10%
Drained</td><td>Initial test group (6 cells)
Control group (3 cells)</td></tr>
<tr><td>3</td><td colspan="2">PROOF CYCLE TESTS (Partially Automatic and Fully Monitored</td></tr>
<tr><td>3.1</td><td>Room Temperature Tests
Level = Select from baseline results
Rates = Select from baseline results
Cycle @ 24 hour orbit for 10 cycles
Cycle @ 2-hour orbit for 40 cycles
Adjustments = Rates and levels as needed during cycling to optimize.</td><td>Electrolyte Level Control<table><tr><th>20 cc Bellows</th><th>10 cc Bellows</th><th>Pillow</th></tr><tr><td>Cell No. 1
Cell No. 5</td><td>Cell No. 2
Cell No. 6</td><td>Cell No. 3
Cell No. 7</td></tr></table>Sealed cell control group</td></tr>
<tr><td>3.2</td><td>EXTREME TEMPERATURE TESTS
Level = Optimum from 3.1 results
Rates = Select from 3.1 results
Cycle @ 24-hour orbit for 10 cycles
Cycle @ 2-hour orbit for 40 cycles
Adjustments = Rates and levels as needed during cycling to optimize</td><td><table><tr><th>Temp. Groups</th><th colspan="3">Level Control</th></tr><tr><th></th><th>20cc Bellows</th><th>10cc Bellows</th><th>Pillow</th></tr><tr><td>0°C</td><td>Cells 1 & 10</td><td>Cells 2 & 11</td><td>Cells 3 & 12</td></tr><tr><td>50°C</td><td>Cells 5 & 13</td><td>Cells 6 & 14</td><td>Cells 7 & 15</td></tr></table>Separators: Optimized for cells 10 thru 15
Control Group: 0°C, 5 cycles at 24 hours and 20 cycles on 2 hour orbit, repeat at 50°C.</td></tr>
<tr><td>4</td><td colspan="2">FINAL CYCLE TESTS (Fully automatic and partially monitored)</td></tr>
<tr><td></td><td>Continuous cycling on shortest possible orbit to establish repeatability.</td><td>Temperature Groups<table><tr><th>0°C</th><th>25°C</th><th>50°C</th></tr><tr><td>Cell Nos.</td><td>Cell Nos.</td><td>Cell Nos.</td></tr><tr><td>10, 11, 12</td><td>1, 2, 3</td><td>5, 6, 7, 13, 14, 15</td></tr></table>Control Group = At all 3 temperatures</td></tr>
</table>